Nuclear Electric Propulsion Development and Qualification Facilities

Prepared for the U.S. Department of Energy
Assistant Secretary for Nuclear Energy

Westinghouse Hanford Company Richland, Washington

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DEVELOPMENT AND QUALIFICATION FACILITIES

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Abstract

This paper summarizes the findings of a Tri-Agency panel; consisting of members from the National Aeronautics and Space Administration (NASA), U.S. Department of Energy (DOE), and U.S. Department of Defense (DOD); charged with reviewing the status and availability of facilities to test components and subsystems for megawatt-class nuclear electric propulsion (NEP) systems. The facilities required to support development of NEP are available in NASA centers, DOE laboratories, and industry. However, several key facilities require significant and near-term modification in order to perform the testing required to meet a 2014 launch date. For the higher powered Mars cargo and piloted missions, the priority established for facility preparation is: (1) thruster developmental testing facility, (2) thruster lifetime testing facility, (3) dynamic energy conversion development and demonstration facility, and (4) advanced reactor testing facility (if required to demonstrate an advanced multiwatt power system). Facilities to support development of the power conditioning and heat rejection subsystems are available in industry, federal laboratories, and universities. In addition to the development facilities, a new preflight qualification and acceptance testing facility will be required to support the deployment of NEP systems for precursor, cargo, or piloted Mars missions. Because the deployment strategy for NEP involves early demonstration missions, the demonstration of the SP-100 power system is needed by the early 2000s.

INTRODUCTION

The President's initiative to return humans to the surface of the moon and then to proceed with human exploration of Mars requires high performance propulsion systems for cargo and human transport. Nuclear electric propulsion (NEP) and nuclear thermal propulsion (NTP) have been identified as enabling technologies to support the Mars piloted mission. Six panels with members from the U.S. Department of Energy (DOE), National Aeronautics and Space Administration (NASA), and the U.S. Department of Defense (DOD) were formed to review technology status and formulate plans for nuclear propulsion development for a piloted mission to Mars in the 2014 to 2019 timeframe.

Re-establishment of the facilities required for development and to conduct performance testing will be one of the pacing activities for the NP Program. Thus, a panel was formed to review testing requirements, resulting facility requirements, available facilities, and, then, recommend a facilities strategy for the participating agencies. This panel formed two subpanels to review the facility needs and availability, and funding priority for NEP and NTP, respectively. The activities of the NEP Facilities Panel are summarized in the remainder of this paper.
**PROCESS**

The Nuclear Electric Propulsion Facilities Panel and the Nuclear Electric Propulsion Technology Panel have common members and often meet jointly to ensure the responsiveness of planning. The development/demonstration strategy which is advocated by the NEP Technology Panel is key to the facilities plan. NEP systems are comprised of five major subsystems, heat source (reactor), energy conversion, power conditioning, heat rejection, and thrusters (Figure 1). These subsystems are relatively independent and can be developed and lifetime or performance demonstrated at the subsystem level. Testing requirements for NEP technologies, components, and subsystems, were provided by the NEP Technologies and the Fuels and Materials Panels (Table 1).

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Interplanetary</th>
<th>Lunar/Mars</th>
<th>Mars Piloted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Precursor</td>
<td>Cargo</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100 kwe,</td>
<td>1-5 Mwe,</td>
<td>500-600 Day</td>
</tr>
<tr>
<td></td>
<td>30-50 kg/kwe</td>
<td>10-20 kg/kwe</td>
<td>10-20 Mwe,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7-10 kg/kwe</td>
</tr>
<tr>
<td>Reactor</td>
<td>SP-100 to Technology Readiness Level (TRL-5), 1996</td>
<td>SP-100 Growth or Advanced, 25 Mw, 2000</td>
<td>Multiple Units</td>
</tr>
<tr>
<td>Thruster</td>
<td>Magnetoplasmadynamic (MPD) or Ion Thruster, TRL-5, 1998; Because of Lifetime Test</td>
<td>NPO or Ion, TRL-5, 2000</td>
<td>NPO, Ion or Advanced, TRL-5, 2006</td>
</tr>
</tbody>
</table>

One of the major assumptions/agreements reached by the NEP Technology and Facilities Panels was that an integrated NEP system test cannot be properly performed on earth. The first test of the entire propulsion system will probably be conducted in space on a demonstration mission. Thus, NEP lends itself to an evolutionary developmental approach where initial precursor missions, such as interplanetary science probes, are conducted with relatively near-term technologies as demonstration tests. Later, higher power cargo and piloted missions will use NEP systems comprised of larger scale subsystems or advanced technologies.

The modularity/independence of NEP subsystems greatly reduced the demand on any individual facility. Most of the NEP subsystems have scalability issues that must be addressed by a rigorous testing program. Thus, all of the recommended facilities are sized to accommodate those components/subsystems needed for the higher power piloted Mars missions. Subsystem integration tests for the reactor/conversion and thruster/power conditioning will be accommodated in the proposed facilities.
OVERVIEW OF AVAILABLE FACILITIES

The facility requirements to meet the testing requirements are provided in Table 2.

**TABLE 2. Major Facility Requirements.**

<table>
<thead>
<tr>
<th>Near Term</th>
<th>Cargo</th>
<th>Piloted A</th>
<th>Piloted B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor</td>
<td>X</td>
<td>50 MWt</td>
<td></td>
</tr>
<tr>
<td>Power Conversion</td>
<td>X</td>
<td>2.5 MWt</td>
<td>5 MWt</td>
</tr>
<tr>
<td>Heat Rejection</td>
<td>X</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>PMAD</td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Thruster</td>
<td>&lt; 0.5 MW</td>
<td>- 2 MW</td>
<td></td>
</tr>
<tr>
<td>Component</td>
<td>Upgrade for</td>
<td>Systems Tests</td>
<td></td>
</tr>
<tr>
<td>and Lifetime Testing</td>
<td>(2 Facilities)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* - No new facility required, available in industry or laboratories.
X - Test facilities supplied by SP-100 Program.

**Facilities to Support Reactor Development**

The SP-100 Flight System Qualification Program is focused on demonstrating technology and components for a 100 kWe power system with thermoelectric conversions. Resolution of the issues of SP-100 technology scalability and (assuming the technology scales), the applicability of the currently planned SP-100 ground test to the larger, higher powered systems required for 5-40 MWe piloted mission is key to the final facilities plan for reactor development.

In the event an advanced reactor technology is shown to provide significant mission performance benefits, an advanced fuels and materials technology program could be accommodated in existing DOE reactors. If the advanced concept is a liquid-metal-cooled fast reactor, the Fast Flux Test Facility and the Experimental Breeder Reactor-II can accommodate all planned testing. If the concept uses a gas-cooled Brayton cycle, a gas loop could be built for the Advanced Test Reactor.

The decision to conduct a large scale test (either with SP-100 or advanced technologies) would require an immediate commitment to develop a test facility to meet environmental, safety, and health requirements. The personnel at the SP-100 Test Site at Hanford provided cost and schedule estimates for modification of the facility to accommodate an order of magnitude increased thermal power (25 MWt). The 8- to 10-year construction schedule was accepted as typical for all potential reactor test sites. In addition to the Hanford Site, detailed reviews were conducted of the Idaho National Engineering Laboratory (INEL) Contained Test Facility, the Oak Ridge National Laboratory (ORNL) Experimental Gas Cooled Reactor, and the Sandia National Laboratories. Because of the perceived requirement for containment and remote locating, future and more detailed site reviews will focus on INEL, ORNL, and Hanford.

**Facilities to Support Energy Conversion Development**

The energy conversion technology used for the piloted Mars mission will most likely be a dynamic system (Brayton, Rankine, or Stirling). NASA and DOE laboratories have been active in energy conversion technology development since the 1960s. Historically, Brayton and Stirling conversion has been developed under the direction of NASA centers and Rankine under the direction of a DOE center.
A high temperature gas loop to support Brayton at ORNL was reviewed extensively, and NASA-Lewis has an ongoing Brayton development program. Brayton testing can be conducted by NASA and ORNL with minor upgrading of existing capabilities. If a full-scale Brayton development program were undertaken, it is likely that both the NASA and ORNL facilities would be used. The ORNL-led activities to demonstrate potassium Rankine in the 1960s and early 1970s provided a technology base. However, none of the facilities required for development of boilers, turbines, and subsystem testing exist today. A significant program would be required to re-establish those facilities, potentially by adapting liquid metal systems now on standby. System studies to determine if these facilities should be re-established are key to the NEP deployment schedule.

Facilities to Support Power Management and Distribution

Facilities for testing power conditioning and power management components and subsystems exist in university, industry, and government laboratories. No additional resource needs were identified by the panel.

Facilities to Support Thruster Development

Ion, magnetoplasmadynamic, and advanced thrusters issues are performance, lifetime, and scalability. There is a need for two test facilities; one for component development testing and a second for long term lifetime and performance testing. The key parameters for thruster testing facilities is the vacuum chamber size required for the megawatt-class thrusters.

Facilities at NASA-Lewis, Lawrence Livermore National Laboratory (LLNL), Oak Ridge National Laboratory, Arnold Engineering Development Center, Los Alamos National Laboratory, and Phillips Laboratories were reviewed for applicability. All the facilities reviewed will require some modification to accommodate the beam dump and achieve appropriate vacuum levels. Because of availability considerations, the facilities at NASA-Lewis, ORNL, and LLNL appear to be the most promising candidates (Sovey, 1991).

NASA-Lewis Research Center's Electric Power Laboratory houses two large space simulation chambers, tanks 5 and 6. Tank 5 is 4.6 m in diameter and 19 m long. Sufficient liquid helium or gaseous helium exists for 8-hour tests. Tank 6 is 7.6 m in diameter and 22 m in length. A NASA-funded rehabilitation of the tank is scheduled to be completed in January 1993. The tank will be capable of dissipating 0.35 MWe. The LLNL Magnetic Fusion Tandem Mirror Test Facility (MFTF) is 10.6 m in diameter and 55 m long. Large amounts of liquid helium storage capability, as well as 8 kW and 3 kW refrigeration liquefier systems, are available onsite. Large magnets from the original program must be removed to allow use as a thruster test facility. The Large Coil Test Facility (LCTF) at ORNL is a 10.7-m-diameter, 9.1-m-high cylindrical chamber with a removable lid, vacuum capability, and liquid helium wall cooling; however, the helium cryosystems were last operated in 1986.

Facilities to Support Heat Rejection Development

A large number of vacuum chambers of appropriate size exist within industry, particularly aerospace companies. Although some additional heat rejection capability may be required, the anticipated costs are within the capability of a typical development program.

RECOMMENDATIONS

The subpanel recommendations are as follows:

1. Complete the SP-100 ground test and demonstration of thermoelectric conversion before the turn of the century to support flight demonstration and precursor missions;

2. Immediately start modifications to provide a thruster development test facility;

3. Immediately start modifications to provide a thruster lifetime test facility;
4. Complete system studies to determine the need for an advanced reactor system versus a scaled SP-100 reactor (the need for a new reactor test facility dependent on results); and

5. Initiate the construction of a dynamic conversion test facility based on results of the systems in item 4.

The thruster, power conversion, and advanced reactor development facilities are highest priority (Table 3). The facility requirements to develop NEP appears to be manageable within current budget expectations.

**TABLE 3. Priority and Availability of the Facilities to Support NEP.**

<table>
<thead>
<tr>
<th>NEP Facility Funding Priority</th>
<th>Existing Facilities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HIGHEST</strong></td>
<td></td>
</tr>
<tr>
<td>Thruster Component Development</td>
<td>Near-Term Fuel Fabrication</td>
</tr>
<tr>
<td>Thruster Lifetime</td>
<td>Near-Term Reactor Ground Test</td>
</tr>
<tr>
<td>Dynamic Energy Conversion</td>
<td>Heat Rejection</td>
</tr>
<tr>
<td>Advanced Reactor Ground Test&lt;sup&gt;0&lt;/sup&gt;</td>
<td>PMAD</td>
</tr>
<tr>
<td>Advanced Fuel Fabrication</td>
<td>Fuels &amp; Materials Examination</td>
</tr>
<tr>
<td>Fuel Element Testing Loops</td>
<td>Unirradiated Fuels &amp; Materials Testing</td>
</tr>
<tr>
<td>Flight Test Support</td>
<td></td>
</tr>
<tr>
<td><strong>MEDIUM</strong></td>
<td></td>
</tr>
<tr>
<td>Advanced Thruster (Particles) Testing</td>
<td>Materials Irradiation Testing</td>
</tr>
<tr>
<td></td>
<td>Safety and Off-Normal Operations</td>
</tr>
<tr>
<td><strong>LOWEST</strong></td>
<td></td>
</tr>
<tr>
<td>Advanced Thruster (Particles) Testing</td>
<td>Control Systems</td>
</tr>
<tr>
<td></td>
<td>Shielding</td>
</tr>
</tbody>
</table>

<sup>0</sup>If reactor > 50 Mw is needed, depends upon mission analysis/choices.

**Acknowledgments**

The contribution of the following NEP Facilities Panel members Sam Bhattacharyya (ANL), John Dearien (INEL), Bob Holcomb (ORNL), and Mike Mahaffey (WHC), and the Air Force’s Phillips Laboratories and Arnold Engineering Development Center provided valuable guidance and technical balance to the facilities panel.

**References**


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